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Effects of aeration rate on maturity and gaseous emissions during sewage sludge composting

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ABSTRACT

This study investigated effects of aeration rate (AR) on maturity and gaseous emissions during sewage sludge composting, sewage sludge and corn stalks as the bulking agent were co-composted at different ARs (0.1, 0.2, 0.3 $L\cdot kg^{-1}$ dry matter (DM)$\cdot min^{-1}$). The thermophilic phase for the low and moderate AR treatments was able meet sanitation requirements, but too short to meet sanitation requirements in the high AR treatment. The high AR treatment was significantly different from the other treatments, and had the lowest electrical conductivity and highest E_4/E_6(absorbance ratio of wavelength 465 and 665 nm). The AR influences the nitrogen variations; high AR compost had the highest NH_4^+-N content and lowest NO_x^--N content. The AR was the main factor influencing compost stability, but the AR had little impact on pH and the germination index. The moderate AR treatment had the highest NH_3 emissions during composting, while the low AR treatment had the highest CH_4 and N_2O emissions. Based on our comprehensive investigation, the recommended AR for sludge composting is 0.2 $L\cdot kg^{-1}$ $DM\cdot min^{-1}$.

1. Introduction

Sewage sludge is an unavoidable by-product of the wastewater treatment process. In recent years, the amount of sewage sludge generated has increased dramatically with the upgrading and expansion of wastewater treatment plants in China. There is an indirect severe risk to human health as a result of the potential pollutant migration to soil and groundwater. Composting is an effective and economical method for the treatment of solid or semisolid biodegradable waste prior to land application. During the composting process, organic matter such as humic acids and nutrients such as nitrogen and phosphorous in sewage sludge can be recycled and transformed into more stable and mature humic substances to enhance plant growth and soil fertility (Külcü and Yaldiz, 2014; Wang et al., 2014).

However, the high moisture content of dewatered sewage sludge (about 80%) causes poor air permeability. Bulking agents are always required to modify the properties of sewage sludge during composting because of the high moisture contents, low C/N ratio and high density of the material. Research has confirmed that use of corn straw as a bulking agent not only improves the maturity of compost, but also reduces gaseous emissions during composting and increases the amounts of reusable nutrients that are present in the compost (Zhang et al., 2013).

The stability and maturity of compost is a primary concern. The stability typically refers to the microbial activity and can be defined by the respiration index or the conversion of various chemical species present in compost organic matter (Gao et al., 2010). In contrast, maturity refers to the amount of degradation of phytotoxic organic substances and is generally measured by GI or plant bioassays (Gao et al., 2010). Stable and mature compost can be applied to soil as an organic amendment to improve plant growth and soil fertility, as well as enhancing the function of soil for carbon sequestration. However, the application of unstable and immature compost may fix nitrogen in the soil and restrict plant growth by competing for oxygen in the rhizosphere and releasing toxic substances (Bernal et al., 2009).

Emissions of gases such as ammonia (NH_3), methane (CH_4) and Nitrous oxide (N_2O) can cause secondary pollution and reduces the environmental benefits of compost. In addition, these substances contribute to nutrient loss from the compost product and therefore lower the quality of the compost product. Two of the byproducts of

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composting, CH_4 and N_2O, are significant greenhouse gases (GHGs). The global warming potential of CH_4 and N_2O, on a 100-yr frame, is 25 and 298 times higher than that of CO_2, respectively (IPCC, 2007). Furthermore, N_2O has been identified as an important ozone layer-depleting pollutant (Ravishankara et al., 2009). Previous studies have shown that 16–74% of initial total nitrogen (TN) is lost during composting (Beck-Friis et al., 2001; Raviv et al., 2002). Among these, 9.6–46% of initial TN is lost in the form of NH_3 (Luo et al., 2014; Jiang et al., 2011) and 0.1–9.9% is lost in the form of N_2O (Shen et al., 2011). Besides, CH_4 is an inevitable byproduct of composting but can be substantially mitigated with proper management. Previous studies have shown that between 0.01% and 0.03% of the initial total organic carbon (TOC) may be lost in the form of CH_4 when manure piles are properly managed (Yamulki, 2006).

The aeration rate (AR) is considered to be the most important factor influencing successful composting (Diaz et al., 2002). Insufficient aeration can lead to anaerobic conditions due to the lack of oxygen, while excessive aeration can increase costs and slow down the composting process via heat, water and ammonia losses. The optimal AR depends on the composition of the raw materials, ventilation methods (Shen et al., 2011; Rasapoor et al., 2009) and oxygen demand of bacteria (Ge et al., 2015; Scaglia et al., 2011). Guo et al. (2012) found that AR was the main factor influencing compost stability; however, AR had no significant influence on the germination index (GI) during the composting of pig feces (Jiang et al., 2015; Guo et al., 2012). Studies have shown that an increased AR can substantially reduce the emission of CH_4 (Jiang et al., 2011, 2015). Within a certain range of ventilation rates, a higher AR may increase the NH_3 emissions (Kim et al., 2009; Jiang et al., 2015). Remarkably, however, Shen et al. (2011) found that higher AR had a lower NH_3 emission. However, Jiang et al. (2011, 2015) found that the AR could significantly affect the N_2O emission; higher ARs increased the N_2O losses from pig manure composting. In contrast, Shen et al. (2011) reported that lower AR increased the N_2O losses from kitchen waste composting.

From an extensive literature search, we conclude that the majority of studies of ARs have focused on the stability and maturity of the compost (Wu et al., 2015; Wang et al., 2011), and water removal during sludge composting (Zhou et al., 2014; Shen et al., 2012). However, there are currently few studies on the effect of AR on maturity and gaseous emissions during sewage sludge composting. Therefore, in the current study, we aimed to comprehensively evaluate the impact of AR on maturity and emissions of NH_3, N_2O and CH_4 during composting using a mixture of sewage sludge and corn straw.

2. Materials and methods

2.1. Material and experimental set-up

Dewatered sewage sludge without anaerobic digestion was collected from a sludge dewatering workshop at the Xiaojiahe wastewater treatment plant in Beijing, China. Corn stalks were obtained from the Shangzhuang experimental station at the China Agricultural University. The cornstalks were passed through a cutting mill to produce pieces with sizes of 2–4 cm. The properties of the feedstocks are shown in Table 1.

In this study, we investigated three treatments with three replicates, 15% cornstalks (proportions of total materials, wet weight) were used as the bulking agent and mixed with sludge. The initial weight (wet weight) of the mixture of sewage sludge and corn straw was 40 kg. This proportion was chosen because 15% cornstalks has been reported to be the optimal additive amount for adjusting moisture content and C/N ratio of composting materials (Zhang et al., 2013; Yang et al., 2013). The continuous ARs were set at 0.1, 0.2 and 0.3 $L \cdot kg^{-1}$ $DM \cdot min^{-1}$ (henceforth named AR = 0.1, AR = 0.2 and AR = 0.3), based on previously reported laboratory studies (Shen et al., 2011).

A specially designed laboratory-scale reactor (60 L in volume, 0.6 m high, 0.36 m inner diameter) was used in this study (Fig. 1). Each vessel was insulated with two layers of stainless steel to minimize heat loss. A stainless steel cap was fitted on the top of each reactor to facilitate its filling and emptying. There were two holes in the lid of each vessel to allow a temperature sensor to be inserted and to allow the gas within the vessel to be sampled. The temperature sensor was connected to a computer, which automatically recorded the temperature data. A 3 mm stainless steel grid was installed at the bottom of each reactor to support the composting bed and to ensure that the added gases were uniformly distributed. There were two holes in the bottom of each reactor to allow the reactor to be aerated (the aeration gas was added using a controllable aquarium pump) and to allow the leachate to drain away. There were three sampling locations with plugs, each 5 cm in diameter, at different heights (0.2, 0.4 and 0.6 m from the bottom). The same composting factor could be found in previous studies (Guo et al., 2012; Shen et al., 2011; Zhang et al., 2013).

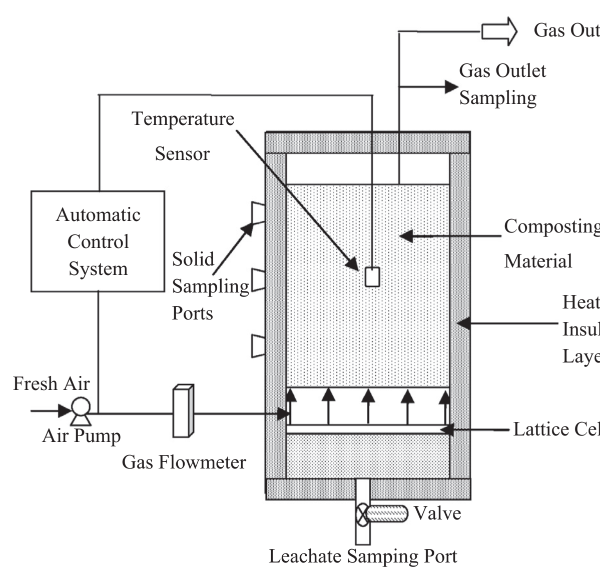

Fig. 1. Diagram of composting vessel.

Table 1
Physical and chemical characteristics of the raw materials.

Materials	Moisture content (%)[a]	TOC (%)[b]	TN (%)[b]	C/N	NH_4^+-N ($g \cdot kg^{-1}$)[b]	NO_x^--N ($g \cdot kg^{-1}$)[b]	pH [a]	Bulk density ($kg \cdot m^3$)[a]
Sludge	85.39 ± 0.85	23.28 ± 0.04	4.00 ± 0.03	5.83	7.76 ± 0.35	0.52 ± 0.04	7.09 ± 0.08	786 ± 3.42
Corn stalks	8.70 ± 0.96	40.12 ± 0.11	1.01 ± 0.02	39.66	0.05 ± 0.01	0.24 ± 0.01	7.24 ± 0.02	183 ± 0.96

TN: total nitrogen; TOC: total organic carbon.
[a] Wet weight basis.
[b] Dry weight basis.